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Mechanical Engineering Department Technical Abstracts

General Editor: R. M. Denney

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Preface

The Mechanical Engineering Department publishes listings of technical abstracts twice a year to inform readers of the broad range of technical activities in the Department, and to promote an exchange of ideas. Details of the work covered by an abstract may be obtained by contacting the author(s).

Overall information about general and current activities of each of the Department's seven divisions precedes the technical abstracts. Specific information about technical activities may be obtained from the division leaders listed at the end of each divisional summary.

Contents

Divisional Activities

Nuclear Test Engineering Division

The Nuclear Test Engineering Division (NTED) provides mechanical engineering and technical expertise for a wide range of activities in three LLNL programs: nuclear test, nuclear systems safety, and energy.

Nuclear Test Program

Our nuclear testing responsibilities involve design, structural evaluation, fabrication, and proof testing of diagnostic and device canisters that position radiation detectors and protect nuclear explosives in an underground environment. We synthesize, procure, and certify the arming and firing systems, and we develop downhole and containment systems to meet zero-detectable radioactivity release requirements. Our advanced development projects include studies of new engineering concepts, analytical and design methods, and diagnostic techniques. In carrying out this work, we strive to improve data quality and field operations, maximize safety, and optimize cost-effectiveness and resource utilization. Included in this programmatic support is spill effects testing under the Liquefied Gaseous Fuels Program.

Nuclear Systems Safety Program

The safety of nuclear power plants and associated facilities is the major concern of the Nuclear Regulatory Commission (NRC). We are responsible for providing technical data relating to reactor safety on which the NRC can base licensing decisions and assessment tools to protect public health and safety. Facilities in the nuclear fuel cycle—processing and fabrication, reactor containment systems, interim waste storage, and spent fuel reprocessing—are considered from the viewpoint of safety and structural integrity.

Our multidisciplinary work is grouped into four categories: seismic and structural safety, reactor engineering, systems/operations, and licensing reviews. The NRC relies on the Laboratory as the primary facility for research on the seismic safety of nuclear power plants. Our multiyear Seismic Safety Margins Research Program (SSMRP), for example, defines the adequacy of seismic design for the safety of nuclear power plants in the U.S. Reactor engineering work involves accident analysis and studies of thermal-hydraulic and fluid-structure interaction phenomena. Systems/operations projects are concerned with risk assessment and control room design reviews. We also provide technical assistance to the NRC licensing staff on reactors operating or under construction.

In addition, our engineering mechanics expertise is applied to specific projects in other areas, including effort for the Magnetic Fusion Program, the Plant Engineering Department, and H, W, and Y Programs.

Energy Program

We provide mechanical engineering support to several of the Laboratory's smaller energy projects and to a number of efforts for the Earth Sciences Department. Current work is under way in oil shale retorting, underground coal gasification, radionuclide migration, spent reactor fuel storage, and geophysics research. We are responsible for designing, building, and operating both laboratory experiments and off-site field engineering tests.

(For further information, contact R.J. Wasley, Ext. 2-9966.)

Nuclear Explosives Engineering Division

The Nuclear Explosives Engineering Division's (NEED) major mission is to support the Laboratory's Nuclear Design Program (NDP) through the engineering and fielding of nuclear devices for testing at the Nevada Test Site. The division also supports the Nonnuclear Ordnance Program, Military Application Program, Organic Materials Division, and H (physics) Division. In addition, NEED performs studies and develops hardware for Y-program, Z Division, and the Defense Nuclear Agency.

The Nuclear Explosives Engineering Division's project teams are dedicated to specific engineering areas: conceptual nuclear design, strategic systems, development and production/liaison for nuclear devices, advanced fission and fusion systems, hydrodiagnostic development, and maintenance and upgrade of many test facilities at Site 300. The Division's applied mechanics group supports Laboratory programs with calculational expertise in solid mechanics and transport phenomena. The auxiliary systems group supports the

Laboratory programs with expertise in high pressure gas technology; NEED also provides staff members for facilities used to conduct high pressure gas and liquid experiments. Certified tubing, valves, and other components or equipment are supplied for hydrogen handling systems.

(For further information, contact R.W. Werne, Ext. 2-8301.)

Weapons Engineering Division

The Weapons Engineering Division (WED) is responsible for engineering activities supporting nuclear weapons development, production, and maintenance of an important portion of the national stockpile. In providing these services, the Division keeps abreast of new developments in safety and weapon control.

The activities include new weapon development, environmental testing, weapon control, initiation systems development, engineering technology, nuclear weapons safety, and special materials procurement. Production work involves communicating product definition and design intent to the DOE contractors responsible for component fabrication and assembly. In addition, active monitoring of the stockpile requires a careful effort in disassembly surveillance of stockpile weapons to ensure that design requirements have indeed been met and to monitor physical changes that may eventually limit the useful life of a weapon.

The Special Materials (SM) office in WED purchases goods and services from the DOE contractors, military commands, and other governmental agencies for all LLNL programs. This office is also responsible for coordinating Laboratory guidance on weapon development activities by the DOE contractors, purchasing special isotopes used in a variety of programs, and providing the DOE with a forecast and management plan on nuclear material usage.

(For further information, contact R.E. Clough, Ext. 2-8296.)

Energy Systems Engineering Division

This division is engaged in a variety of work to provide mechanical engineering support to the Laser (Y) Program in two major categories: Laser Isotope Separation (LIS) and Inertial Confinement Fusion (ICF). In the LIS program, coherent laser light is used to selectively photoionize atoms of a given isotope in a material containing several isotopes. The ionized atoms can then be separated and enriched using extractor/collectors. The ICF effort is directed at understanding the basic physics problems associated with imploding small fusion targets with high power lasers, and at developing a fusion process to provide an unlimited source of power for use during the next century. Each major category has both military and civilian applications.

(For further information, contact J.E. Keller, Jr., Ext. 2-7582, or J.R. Hauber, Ext. 2-6027.)

Engineering Sciences Division

The Engineering Sciences Division (ESD) provides complete technical services to LLNL programs for materials characterization, engineering measurements, nondestructive evaluation, and mechanical systems design and evaluation. The Division has more than 20 separate laboratories and facilities that are organized into sections responsible for specific technological areas.

The Materials Test and Evaluation Section provides mechanical testing, such as ASTM standard tests and special tests tailored to individual customer requirements. To characterize and improve engineering designs, the section carries out developments in the fields of acoustic emission, fracture mechanics, high-rate material response, experimental stress analysis, and composite materials.

The Engineering Measurements Section is engaged in work ranging from the design of a single transducer to the fielding of complete measurements systems. Service for the calibration and installation of transducers and accelerometers is also available.

The Nondestructive Evaluation Section provides inspection and diagnostic testing services for LLNL programs. X-ray and gamma source radiography, radiation gauging, ultrasonics, eddy current, dye penetrant, magnetic particle, and holographic techniques are available.

The Engineering Design Section performs design, analysis, and mechanical fabrication in support of the Chemistry and Materials Science Department and many ESD projects. The section is particularly experienced in automated machine design, composites processing and fabrication, tritium handling, and mass spectrometry.

The Life Sciences Section provides mechanical engineering support for Biomed and Environmental Research, Hazards Control, and Toxic Waste Management programs. Examples of developments to meet the varied requirements of these groups include a cell sorter in Biomed, personnel dosimetry equipment in Hazards Control, and storage and/or burial containers for toxic wastes.

The LLNL Plutonium Facility is managed by the Chemistry and Materials Science Department with operational support provided in part by ESD. The Plutonium Engineering Section in ESD provides engineering design, fabrication, and testing services for the Facility and its users.

The Engineering Information Section serves the Laboratory's Mechanical, Electronics, and Plant Engineering Departments through the Engineering Record Center, which archives, reproduces, and distributes engineering designs. The section also maintains two libraries containing technical references, government and industry specifications, and vendor data. A Specification Engineering and Standards Group assists in defining requirements for acquiring equipment, and stores stock items from outside manufacturers.

(For further information, contact J.P. Mahler, Ext. 2-8360.)

Magnetic Fusion Engineering Division

The Magnetic Fusion Engineering Division (MFED) supports the LLNL physics programs in four principal areas:

- Magnetic fusion energy (MFE) confinement experiments.
- MFE development and technology.
- Particle beam development.
- High energy physics.

The four areas share a common technological base, although their individual goals differ greatly. Each area requires support from essentially all mechanical engineering disciplines and from specialists in normal and superconducting magnetics, cryogenic systems, vacuum systems, high-voltage components, and nucleonics.

Our role in the MFE confinement experiments is to provide systems engineering and to design and fabricate mechanical hardware. The research in magnetic mirror confinement of nuclear fusion reactions is expected to lead to utilizing deuterium, an isotope of hydrogen present in sea water, as a nearly inexhaustible energy source. The major confinement experiments are the Tandem Mirror Experiment (TMX), Beta II (formerly 2XIIB), and the Mirror Fusion Test Facility (MFTF).

In MFE development and technology, our mission is to develop the technical base and engineering skills necessary to meet future needs of magnetic confinement systems. Our active programs are the development of a multifilamentary Nb_3Sn superconductor, high-vacuum technology, and fusion reactor studies. Basic research and development are emphasized to lay the groundwork for future fusion experiments.

The particle beam development program, funded by the Defense Advanced Research Projects Agency (DARPA), involves building high-current, high-voltage, electron accelerators. Such accelerators are of interest for basic physics research and in the weapons community. The present program calls for developing two accelerators, the Experimental Test Accelerator (ETA) and the Advanced Test Accelerator (ATA), a 10-kA, 50-MeV machine.

Our role in high-energy physics is to provide tools with which to pursue fundamental understanding of energy and matter. Technical support is provided for experiments performed at the 100-MeV electron linear accelerator (Linac), three 400-keV dc high-current accelerators, a 3-MeV electrostatic accelerator, a 6-MeV tandem electrostatic accelerator, and a 76-cm cyclotron.

The MFED consists of seven project groups plus a division office.

(For further information, contact H.L. Galles, Ext. 2-6750.)

Materials Fabrication Division

The Materials Fabrication Division, a multidisciplinary organization in the Mechanical Engineering Department, provides services that are not available from commercial sources. The number and diversity of LLNL research efforts make this division one of the Laboratory's largest. We have approximately 445 highly skilled persons and more than 3,700 pieces of equipment in our inventory.

With these facilities and the special capabilities of our staff we provide services in the fields of optics, welding, vacuum process, glass, plastics, sheet metal, metal finishing, metrology, forming, inspection, and assembly, as well as conventional and numerically controlled machining of metals, high explosives, and ceramics.

In-house fabrication services are available for all LLNL programs when requirements call for:

- Fabrication capabilities not readily available elsewhere.
- Rapid turnaround time.
- Handling of materials that are toxic, radioactive, or classified.

In addition, the Division's facilities are used to develop improved manufacturing techniques and to advance machine tool research. Our operating philosophy is to satisfy the mechanical fabrication need of the programs, consistent with priorities set by those programs.

(For further information, contact D.K. Fisher, Ext. 2-7643.)

Publication Abstracts*

T. H. Batzer and W. R. Call, *Mirror Fusion Vacuum Technology Developments,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89304 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Mirror fusion experiments and projected mirror reactors have vacuum requirements that are unique. Among them are the very high continuous pumping speeds, 10^7 to 10^8 liters/sec for D_2, T_2 and He that must be accomplished by internally deployed cryogenic pumps, and the high heat flux, water-cooled neutral beam dumps that are vulnerable to burn throughs and water leaks. Both these systems along with the superconducting magnets, require very large quantities of water, liquid nitrogen and liquid helium to be circulated through their systems within the vacuum chamber.

The development of a continuous cryopump for D-T pumping is successfully under way. A prototype of a continuous cryosorption pump for He is under construction. Its design and operation will be discussed.

The several thousand m^2 of liquid nitrogen-cooled thermal shielding for the cryopumps and superconducting magnet make the early detection of a water leak from the neutral beam and halo plasma heat dumps a concern. Several water leak detection tests have been done with different liquid nitrogen cooled shield geometries. The results and interpretation of these tests will be discussed.

Detecting leaks and locating them in the cryosystems require special techniques especially for the superconducting magnets that are not protected by a guard vacuum. The development and application of these techniques will be discussed.

T. G. Beat and W. K. Kelley, *Thermal Outgassing Behavior of Electrodeposited Black Chromium,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-82797 Rev. 1 (1983). Prepared for the American Electroplaters' Soc. 70th Annual Techn. Conf., Indianapolis, IN, June 26–30, 1983.

The outgassing characteristics of electrodeposited black chromium were determined because of interest in using this coating in vacuum applications. Data obtained for a variety of conditions led to the conclusion that this coating is acceptable for use in optical transport networks and plasma physics experiments. The outgassing rate for an unbaked coating was 3×10^{-10} Torr liters/s/cm^2.

D. D. Berger, *Step Brazing a Multi-Target TRAX,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-88285. Prepared for the *Welding Journal* **62,** 41 (Oct. 1983).

Fabrication of a target holder for a multi-target transmission anode x-ray tube (TRAX) involved joining of five different materials. The TRAX will generate a nearly mono-energetic x-ray beam useful for instrument calibration and dosimetry studies. Each of three different targets will provide different energy. The design will allow the experimenter to place a different target in front of the electron beam without breaking vacuum each time.

This report describes the procedure used for attaching three 12.7-mm (1/2 in.) diameter targets—made of tungsten, gold and uranium 238 (D-38)—to an OFHC copper support bar. It also describes the joining of the copper bar to a welded stainless steel bellows and flange.

J. H. Berkey, E. N. C. Dalder, Y. Chang, G. L. Johnson, G. H. Lathrop, D. L. Podesta, and J. H. Van Sant, *Use of Fusion Welding Techniques in Fabrication of a Superconducting Magnet Thermal Shield System,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87700 (1983). Prepared for the 64th Annual Conv. American Welding Soc., Philadelphia, PA, April 25–29, 1983.

The 750,000-pound superconducting magnet for the Mirror Fusion Test Facility was successfully tested at its full design conditions, demonstrating that large superconducting magnet systems are now an available technology for magnetic fusion energy. Several arc welding processes were used to fabricate a thermal shield system for the magnet. The magnet, shaped like two

* The abstracts are arranged alphabetically by first author's name.

interlocking folded donuts, created a magnetic field which is 150,000 times the average magnetic field at the earth's surface and is strong enough to contain hydrogen fusion plasmas. To achieve superconductivity and the resulting high magnetic fields, the entire magnet structure was cooled to near absolute zero (4 K).

Liquid nitrogen (LN) cooled thermal shields covered the magnet surfaces and limited heat transfer to the magnet to only a few hundred watts, well within design limits. The thermal shields consist of LN cooled panels that cover all exterior surfaces of the superconducting magnet. The panels are supported by low thermal conductance brackets that are fastened to the magnet's structure. Supply and return flow manifolding is arranged to direct LN flow in the bottom and out the top of each panel to obtain complete filling and good heat transfer during operation.

A commercial heat transfer panel* was fabricated to LLNL specifications. The panel is GTA-welded along the edges of two Type 316L stainless steel sheets and pneumatically inflated. Supply and outlet flow tubes are included at specified locations on the panel edges. Resistance welded seams in panel-interiors channel flow to all regions within the panel.

The piping system is fabricated from Type 316 stainless steel. Tubing, fittings, and bellows were manufactured to LLNL specifications by commercial suppliers. The system is designed to provide the required flow distribution, to withstand operating temperature excursions, and to provide compliance for large relative displacements between the magnet and shields caused by thermal and mechanical movements. The tubing is located outside the panels and is supported by brackets welded to the panel surfaces.

Supports for the shields are fabricated from NEMA G-10 fiberglass-epoxy composite. Each support is fastened to the magnet with four stud-welded bolts and attached to the panels with one bolt. Each panel has four supports and each support contributes less than 0.1 W heat transfer to the magnet.

Other design requirements for the shield system include:

- 1,000 thermal cycles from 300 to 70 K.
- 150 psig working pressure.
- Maximum surface temperature during magnet operation of 90 K.

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* Panels are "Temp-Plate" heat transfer panels manufactured by the Paul Mueller Company.

More than 3,000 welds that joined lengths of tubing to each other and to panels were made using the gas-tungsten-arc (GTA) process. Two semiautomatic orbital GTA units were used to fabricate manifold subassemblies. This method provided a rapid and reliable process for making weld-joints in tubing ranging from 1/2 to 3 in. diameter.

Manual GTA welding was used to weld some of the joints while installing subassemblies and panels on the magnets. The more reliable orbital GTA process was preferred for making all tube-joint welds, but limited clearances between piping and panels on the magnets provided insufficient space for the orbital weld head in some locations. High levels of weld leak tightness and structural integrity is required during operation. The initial acceptance rate of the orbital GTA welds was more than 98% and of the manual GTA welds, more than 96%.

Acceptance testing was done by leak testing all welds with a helium mass spectrometer system. Subassemblies were tested on the bench. Panels were tested by the manufacturer after internal pressurization and thermal-cycling. Acceptance rate of all panels was more than 99%.

More than 4,500 stud-welded bolts attach panel supports to magnet surfaces. Using 1/4-in. diameter Type 304 stainless steel bolts, a stud-welding schedule was developed which produced over 100 samples that withstood 160% of the design torque. During installation, studs were proof-tested by torquing to 100% of design torque. The rejection rate was less than one percent. Repairs were made by spot-grinding the magnet surface and welding another stud in the same location, with a zero rejection rate. Load-tests of bracket and stud-welded assemblies showed that the assembly could support a 1,000-pound compression load and 500-pound side load, providing a safety factor of above 4.

An appreciation of the difficulties experienced by operators of the GTA and stud welding units can be gained by noting that all principal working surfaces of the magnet are inclined at 45 degrees, resulting in all stud welds being made in an "out-of-position" orientation and all GTA welds being made in either the vertical or overhead positions. Nevertheless, GTA and stud welding was successfully adopted to overcome these difficulties.

Success of the thermal shield system is evident by the results of acceptance tests performed with the magnet and all its ancillary equipment.

During these tests the thermal shield system was:

- Thermally cycled several times from atmospheric to LN temperatures.
- Pressure cycled several times from 0 to 5 atmospheres.
- Operated for more than 500 hours at LN temperatures and in a vacuum environment of less than 10^{-5} Torr.
- Operated in a magnetic field up to 60,000 gauss.
- Exposed to a rapidly collapsing magnetic field of more than 250 gauss per second.
- Drained of all LN in only a few minutes, without any weld-failures.

M. P. Bohn, L. C. Shieh, J. E. Wells, L. C. Cover, D. L. Bernreuter, J. C. Chen, J. J. Johnson, L. L. George, S. E. Bumpus, R. W. Mensing, W. J. O'Connell, and D. A. Lappa, *Application of the SSMRP Methodology to the Seismic Risk at the Zion Nuclear Power Plant,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53483 (1983). Prepared for the Nuclear Regulatory Commission, NUREG/CR-3428.

The Seismic Safety Margins Research Program (SSMRP) is a U.S. NRC-funded multiyear program conducted by Lawrence Livermore National Laboratory (LLNL). Its goal is to develop a complete fully coupled analysis procedure (including methods and computer codes) for estimating the risk of an earthquake-induced radioactive release from a commercial nuclear power plant. The analysis procedure is based upon a state-of-the-art evaluation of the current seismic analysis and design process and explicitly accounts for uncertainties inherent in such a process.

The SSMRP is the first effort to trace seismically induced failure modes in a reactor system down to the individual component level, and to take into account common cause earthquake-induced failures at the component level. This report presents the results of our seismic risk analysis of the Zion nuclear power plant using the SSMRP methodology.

The risk analysis included a detailed seismological evaluation of the region around Zion, Illinois which provided the earthquake hazard function and an appropriately randomized set of 180 time histories (having pga values up to 1.8 g). These time histories were used as input to dynamic structural response calculations for four separate Zion buildings. Detailed finite element models of the buildings were used. Calculated time histories at piping support points were then used to determine moments throughout critical piping systems. Twenty-one separate piping systems were analyzed. Finally, the responses of piping and safety system components within the buildings were combined with probabilistic failure criteria and event tree/fault tree models of the plant safety systems to produce an estimate of the probability of core melt and radioactive release due to the occurrence of earthquakes.

The base case is our best estimate of the configuration of the Zion plant, its current normal and emergency operating procedures. Some important assumptions as to the consequences of certain localized structural failures were made. For this base case, the median probability of core melt was computed to be 1E-5 per year. The upper (90%) bound on the core melt-probability was computed to be 2E-3 per year, and the lower (10%) bound was computed to be 1E-7 per year.

Three additional cases were analyzed to test the effects of fundamental assumptions made for the base case. The base case probability of core melt and radioactive release was due primarily to (1) failure of pipes between the reactor building and the auxiliary building caused by relative motion between the two buildings and soil failure and uplift of the containment basemat, and (2) loss of on-site emergency AC power caused by failure of the service water pump enclosure roof slab, and the assumption that all six service water pumps would be damaged by the falling slab. If the assumptions as to the consequences of the basemat uplift and roof slab are removed, then it is found that the probability of core melt and release are reduced by a factor of 2.

In addition, the base case analyzed assumed that the operator could perform a "feed and bleed" operation to provide core cooling in the event the auxiliary feedwater system had failed. If this assumption is not made, the core melt probability increases by a factor of 3. The radioactive release (expressed in terms of man-rem/year) increases by only 13%, however, because the additional accident scenarios lead to release via basemat melt-through rather than overpressure failure of the containment.

Other cases were analyzed which showed that including the local site soil profile under the plant was an important effect, while the effects of structure-to-structure interaction and the assumption of rigid foundations were not significant. Finally, several cases were analyzed showing the effects of correlation between responses in the plant due to the common ground shaking, and correlation between fragilities.

M. P. Bohn, J. E. Wells, L. C. Shieh, L. E. Cover, and R. L. Streit, *An Assessment of Potential Increases in Risk Due to Degradation of Steam Generator and Reactor Coolant Pump Supports,* Lawrence Livermore National Laboratory, Livermore, CA, UCID-19719 (1983).

During the NRC licensing review for the North Anna Units 1 and 2 pressurized water reactors (PWRs), questions were raised regarding the potential for low fracture toughness of steam generator and reactor coolant pump supports. Because other PWRs may face similar problems, this issue was incorporated into the NRC Program for Resolution of Generic Issues. The work described in this report was performed to provide the NRC with a quantitative evaluation of the value/impact implications of the various options of resolving the fracture toughness question.

This report presents an assessment of the probabilistic risk associated with nil-ductility failures of steam generator and reactor coolant pump structural support systems during seismic events, performed using the Seismic Safety Margins Research Program codes and data bases.

Two cases were analyzed. In Case 1 the support failure was assumed to occur at the safe-shutdown earthquake (SSE), while in Case 2 the systems were assumed to fail at twice the SSE. The public dose assuming reduced capacity supports was found to be about 32 man-rem/year (Case 1) and 12 man-rem/year (Case 2), compared to the base case (normal support capacity) of 6.6 man-rem/year.

Although this analysis was performed using the seismic hazard curve, and logic and structural models specific to Zion, the resulting risk numbers are *in no way* to be construed as applying to the Zion plant, because the fracture toughness of the Zion supports has been found to satisfactorily meet all design requirements.

R. H. Bossi and J. R. Ambrosino, *Penetrant and Magnetic Particle Inspection for Material Integrity,* Lawrence Livermore National Laboratory, Livermore, CA, UCID-19824 (1983).

The Nondestructive Evaluation Section at Lawrence Livermore National Laboratory provides penetrant and magnetic particle inspection services. These two techniques are used on materials and fabricated parts to test for surface or near-surface cracks and defects that may limit serviceability. The use of these methods assures a trouble-free service life, improves safety, and is cost-effective. The inspection of material at appropriate stages of fabrication can result in real savings of time and effort by detecting potentially unusable material before extensive machining and finishing have been performed.

Norman J. Brown, Robert R. Donaldson, and Daniel C. Thompson, *Fabrication of Machined Optics for Precision Applications,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89674 (1983). Prepared for the Society of Photo-Optical Engineers, Garmisch-Partenkirchen, West Germany, April 12–14, 1983.

This paper will discuss the current state of optical fabrication employing precision machining. While it is a perspective based upon both our own work and that of others, it lays no claim to being a comprehensive survey.

Today state-of-the-art precision machining can produce surfaces to tolerances consistent with visible and near-visible wavelength optical applications. These new technologies extend not only the range of geometries, but the range of materials, and in some cases, even the range of finishes available to the optical designer. These technologies are not an abrupt step increase in capability but the result of several decades of advances in metrology, computer technology, servomechanisms, bearing technology, tooling and environmental control.

The most precise work today is done with single point diamond tooling, but we find the commonly used term, "single point diamond turning" (SPDT) an increasingly inadequate descriptor of the synergistic union of technologies that is the precision machining of today. With the entrance of cubic boron nitride (CBN) into the field, it is no longer the exclusive domain of diamond. The same grouping of technologies is being applied to grinding on a small scale, so it is no longer the restricted domain of single point tools. Yoshioka et al., for example, have reported 0.2 micrometer resolution on a new surface grinder which has produced plastic regime grinding on brittle materials such as fused silica. Finally, even on turning machines, we are increasingly seeing flycutting and occasionally, on small work, even dual spindle flycutting of flats and spheres, so it is no longer just turning.

With third generation machines coming on line, precision optical machining is no longer a novelty, but is entering the realm of a maturing technology. As metrology techniques advance to a precision of a few atom layers, those gains due primarily to metrology are slowing down and future gains will be seen to result from careful design, attention to increasingly miniscule detail and to tooling and materials studies. With maturity, the field is less hampered by the claims of the overenthusiastic and the fears of the ignorant. It is seen less as a competition to the optical industry than as a process competing for their attention; able to extend their capabilities and productivity. While some components can be carried to completion, many more require the attention of the traditional optical finisher. To give a feel for the state and pace of the field, this paper will outline the development of the technology, compare its advantages and limitations with traditional methods of surface generation, describe a few of its more novel applications, discuss some elements of machine design and necessary approaches to metrology and finishing.

A. K. Chargin, M. O. Calderon, and T. L. Moore, *Recent Operating History and Current Axisymmetric Coil Additions to Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89250 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Since the end of construction in December 1981, we have operated TMX-U through seven experimental runs. In the first two runs, we concentrated on making the hardware operational, conditioning the walls, and generating initial plasma. After that we proceeded through the planned experimental sequence: generating sloshing ions, developing electron cyclotron resonance heating (ECRH) start-up techniques, repeating conventional tandem results, producing hot electrons, modeling MFTF-B start-up, pumping cold ions from the end plug, generating thermal barrier, and running the machine in the negative mode. These issues were studied in a series of five runs, each lasting an average of four months. Typically each run consists of an at-air cycle lasting one month, a work-up period of one month, and two months of data taking. During the at-air time we configure the machine for the coming experiment and do the required maintenance. The current air cycle involves a major reconfiguration of the machine. This reconfiguration consists of: a) installation of a high-field axisymmetric mirror (called throttle) at each end of the central cell, b) increasing the magnet power by 50%, c) adapting the vacuum envelope to the new coils, and d) making several smaller changes to other subsystems. The experimental goals of the new configuration are: a) to increase radial confinement time for central-cell ions, b) to investigate the trapped-particle instability, and c) to provide a facility for development of improved methods for pumping unwanted ions from potential barrier regions. All of the above experimental goals are accomplished by closely managed control of machine configuration, of costs, and of schedules.

A. K. Chargin, C. C. Damm, and W. C. Turner, *Quality Assurance (QA) for Operations of Fusion Machines as Applied to the Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89257 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Even the best QA plan and its successful execution during construction of a typical fusion machine will produce hardware that is inoperative for some fraction of time. Operating a machine with its hardware out of tolerance, with respect to the specifications, does produce data which is the goal of the experiment. However, a majority of such data are difficult to interpret and may not contribute to understanding the behavior of the experiment. In addition, few fusion machines just operate. The majority of the machines are in the process of being rebuilt and/or added to as they operate. These modifications can keep an otherwise operational machine from running. To insure quality in operation of TMX-U, we employ a series of QA procedures. We start with technical milestones, schedules, and budgets that are all negotiated with DOE. Within that framework we implement a total management scheme which, in addition to normal schedule and budget controls, includes: detailed experimental run plans, definition of machine configuration required to accomplish the run plan, subsystem work-ups, instrument calibration, verification of subsystem operation, and repetition of standard physics plasma parameters. All of these activities must be completed before taking data for the experimental run plan. If a subsystem is found out of tolerance, a decision must be made either to delay operation and fix the problem or to continue on a contingency-run plan which should still produce the data relevant to the project milestones. In this presentation we discuss those QA procedures for TMX-U operations that we apply to minimize the cost and time required to achieve the technical objectives.

R. C. Chun and T. Y. Chuang, *Impact Analyses After Pipe Rupture,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86247 (1983). Prepared for the Intern. Conf. on Structural Impact and Crashworthiness, London, U.K., July 16–20, 1984.

From 1979 through 1982, a computer code entitled "Whip and Impact of Piping Systems" (WIPS) was developed by Professor G. Powell of the University of California at Berkeley under contract from the U.S. Nuclear Regulatory Commission (NRC) to the Lawrence Livermore National Laboratory (LLNL). WIPS is a special purpose implicit finite-element computer code for the structural analysis of pipe whip dynamic effects following a postulated pipe rupture in a nuclear power plant. The code can be used to determine: (1) the overall motions of a piping system, (2) the detailed deformations of individual piping components, and (3) the impact forces and local deformations at points of pipe-to-pipe or pipe-to-wall impact. Some of the outstanding features of WIPS are:

1. Its straight or curved pipe element can take ovalling into consideration.
2. Strain-rate effects can be included for all of its elements (beam, pipe, U-bar, gap-friction, and shell).
3. Nonlinear kinematics includes large displacements and large strains and material nonlinearities are represented by the Mroz plasticity model.
4. Time integration can employ either the Newmark procedure or the Hilber-Hughes-Taylor procedure.
5. Multi-level substructuring, general modal displacement slaving, and surface-to-surface contact computations are available.

The WIPS code has been validated only to a limited extent due to the scarcity of experimental data. In the last several years, the French Commissariat à l'Energie Atomique (CEA) has conducted a series of pipe whip tests at their Aquitaine II facility. Under an international exchange program, the French CEA provided the USNRC with a detailed test description and the results of their impact tests. In this work, WIPS has been used to successfully reproduce two of these experiments. The technique proposed by Garcia, etc. is adopted by us in a modified format to circumvent the necessity of expensive three-dimensional shell analyses. This technique involves: (1) modeling the pipe with one-dimensional pipe elements, and (2) taking into account the local stiffness of the impact zone (elbow), as determined experimentally by the French CEA, with the use of a fictitious U-bar element.

The WIPS results (including whipping time, time to obtain maximum load, vertical velocity at impact, and the maximum impact force) are found to compare very favorably with the French experimental data as well as the French computer code TEDEL.

I. R. Clarkson and W. S. Neef, *Configuration and Layout of the Tandem Mirror Fusion Power Demonstrator,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89438 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Studies have been performed during the past year to determine the configuration of a Tandem Mirror Fusion Power Demonstrator (FPD) machine capable of producing 1750 MW of fusion power. FPD is seen as the next logical step beyond MFTF-B toward a power reactor. The design of the FPD machine allows a phased construction: Phase 1, a hydrogen or deuterium checkout machine; Phase 2, a D/T "breakeven" machine and; Phase 3, a development of the Phase 2 machine to provide net power and act as a reactor demonstrator. Phasing of the machine is very important to the development of remote handling equipment and of the components that will ultimately be required to be remotely handled. Phasing also permits more modest funding early in the program with some costs committed only after reaching major milestones. The design philosophy adopted for FPD used the Mirror Advanced Reactor Study (MARS) machine as a baseline, but with a shorter central cell—75 m compared to 150 m. Component design improvements since the MRS design was frozen have allowed the design of smaller end cell magnets and a smaller conductor cross section for the central cell coils. Ease of assembly and disassembly were important criteria that led to a Phase 3 design which is capable of being handled remotely. Remote maintenance and/or replacement of all components of the machine has been reviewed and methods for removal and replacement devised. A structure supporting all of the end cell C-shaped magnets has been designed enabling the magnets to be assembled to the structure outside the vacuum vessel and the complete assembly put in place in the vacuum vessel (and withdrawn from it) on rail-mounted transhaulers. It is also possible, in this design, to assemble only the support structure in the vacuum vessel and then load the coils into the structure.

F. E. Coffield, B. Felker, N. C. Gallagher, Jr., L. R. Pedrotti, B. W. Stallard, D. W. Sweeney, and E. W. Wyman, *Polarizing Holographic Reflector for Electron Cyclotron Resonant Heating (ECRH) on the Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89236 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

We describe a reflector designed to convert the high-power TE_{01} output of the circular waveguide system into a linearly polarized gaussian intensity pattern in the plasma. The design, fabrication and performance of the reflector are discussed as well as its capabilities and limitations. The reflector is a computer-generated holographic optical element incorporating a twist polarizer. It has a modulated surface profile that applies the appropriate phase correction necessary to convert the TE_{01} donut mode into a gaussian intensity pattern. Onto this modulated surface, a set of grooves is milled to make the twist polarizer. The grooves are a quarter wavelength deep and oriented so that the incident circular polarization is converted to the linear polarization necessary for maximum plasma absorption. The reflector was fabricated using a five-axis numerically controlled milling machine. Results are presented for low power tests used to determine the beam pattern and the degree of cross-polarization. High power testing has verified that arcing across the grooves does not occur.

F. E. Coffield, D. D. Lang, R. D. Stever, and S. R. Thomas, Jr., *Microwave Interferometer Using 94-GHz Solid-State Sources,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89244 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

A four-channel 140-GHz microwave interferometer system has operated on TMX-U for more than one year. This system consistently provides high resolution (180 or 6×10^{11} cm^{-2}) line density measurements. Its limitations include difficulty in changing measurement locations and the relative unreliability of klystrons, extended interaction oscillators, and high voltage power supplies. These limitations have prompted us to design a new interferometer system to be used on Tandem Mirror Experiment Upgrade (TMX-U) and on Mirror Fusion Test Facility-B (MFTF-B). The new 94 GHz system consists of modular single-channel units designed for high reliability. The magnetically shielded interferometers will be mounted close to the machine, which allows the use of lower power solid state sources with mean time between failures (MTBFs) of 100,000 hours. A digital phase comparator has been developed that provides high resolution linear phase measurements for carrier frequencies over 60 MHz. Many factors were involved in choosing the 94 GHz operating frequency, including synchrotron noise, high electron temperature nonlinearity, and plasma absorption. Several antenna designs are planned for the various measurement locations, including single- and double-pass configurations. We are using a ray tracing code to evaluate the antenna and retroreflector designs. We present the TMX-U and MFTF-B antenna designs along with the test results of a prototype of the 94 GHz microwave system and processing electronics. The unique problems associated with diagnosing a high electron temperature plasma in the presence of electron cyclotron resonant heating (ECRH) will also be discussed.

G. W. Coutts, M. L. Coon, R. S. Hornady, D. D. Lang, and N. P. Lund, *Development of Procedures to Ensure Quality and Integrity in Tandem Mirror Experiment Upgrade (TMX-U) Diagnostic Systems,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89245 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The diagnostic systems for TMX-U have grown from 11 initial systems to more than 20 systems. During operation, diagnostic system modifications are sometimes required to complete an experimental objective. Also, during operations new diagnostic systems are being developed and implemented. To ensure and maintain the quality and integrity of the data signals, a set of plans and systematic actions are being developed. This paper reviews the procedures set in place to maintain the integrity of existing data systems and ensure the performance objectives of new diagnostics being added.

L. E. Cover, M. P. Bohn, R. D. Campbell,* and D. A. Wesley,* *Handbook of Nuclear Power Plant Seismic Fragilities Developed for the Seismic Safety Margins Research Program,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53455 (1983). Prepared for the Nuclear Regulatory Commission, NUREG/CR-3558.

The Seismic Safety Margins Research Program (SSMRP) is a U.S. NRC-funded multiyear program conducted by Lawrence Livermore National Laboratory (LLNL). Its goal is to develop a complete fully coupled analysis procedure (including methods and computer codes) for estimating the risk of an earthquake-induced radioactive release from a commercial nuclear power plant. As part of this program, calculations of the seismic risk from a typical commercial nuclear reactor were made. These calculations required a knowledge of the probability of failure (fragility) of safety-related components in the reactor system which actively participate in the hypothesized accident scenarios. This report describes the development of the required fragility relations and the data sources and data reduction techniques upon which they are based. Both building and component fragilities are covered. The building fragilities are for the Zion Unit 1 reactor which was the specific plant used for development of methodology in the program. Some of the component fragilities are site-specific also, but most would be usable for other sites as well.

E. N. C. Dalder, W. Ludemann, and B. Schumacher, *Thermal Stability of Four High-Strength, High-Conductivity Copper Sheet Alloys,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89034, Rev. 1 (1983). Prepared for the U.S. Department of Energy Copper Workshop, Washington, DC, April 14–15, 1983.

The object is to determine the effects of the thermal treatments used during diffusion bonding, forming, and tritiding 50-cm-dia. RTNS-II targets on the room-temperature tensile properties of Amzirc, MZC, Elbrodur RS, and Glid-Cop copper alloy sheets of 0.04-in. thickness.

D. J. Diaz and S. E. Benson, *Field Metallography Aids NDT of Evaluation of Indications in Turbine Main Column Horizontal Plate Welds at Power Plant,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89378 (1983). Prepared for the 16th Annual Technical Meeting of the Intern. Metallographic Soc., Calgary, Alberta, Canada, July 25–28, 1983.

An evaluation of indications in the main turbine building column horizontal plate welds was conducted by the joint efforts of field metallography and nondestructive examinations. The turbine building main column horizontal plate welds were selected at random and were inspected to find discontinuities, metallurgical evaluation of the discontinuities, analysis of any failure modes, and determination of the best repair techniques.

The welds were made with prequalified joints in accordance with AWS D1.1-77 and required only visual inspection. More sensitive inspection methods were applied to the welds in order to better define the indications found with the visual inspections.

Cracks were found in 17 field welds and in two test plate welds. The causes of the cracking are related to the weld design and installation procedures. Three field welds were rejected because of the depth of the cracks. The NDT inspections, evaluations, method of field metallography, analysis and conclusions are discussed with recommendations for corrective actions in the following report.

J. W. Dini, *Electroplating and Vacuum Deposition—Complementary Coating Processes,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89209 (1983). Prepared for Interfinish 84, 11th World Congress on Metal Finishing, Jerusalem, Israel, October 21–26, 1984.

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This paper shows that electroplating and vacuum deposition can be highly complementary coating processes. Applications wherein the two processes have been used are reviewed and then three specific examples are presented where a combination of electroplating and vacuum deposition solved unusual coating requirements at Lawrence Livermore National Laboratory.

J. W. Dini, *Lead and Lead Alloys,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-88372 (1982). Prepared as Chapter 11 for *The Properties of Electrodeposited Metals and Alloys,* W. H. Safranek, Ed. (American Electroplaters' Soc.), 2nd ed.

Lead and lead-tin alloys are usually deposited in fluoborate solutions. Lead electrodeposits are not used for decorative purposes because they have a relatively mat appearance which gradually becomes duller as surface films form. These films, however, are normally protective and enable lead to withstand corrosion in many aggressive environments. Electrodeposited lead is used on structural steel parts, supports for electrical power lines, linings of brine refrigeration tanks, chemical equipment, gas bottles and storage battery parts. Alloys with 4 to 10% tin are also used for corrosion protection of steel. Lead and lead-tin deposits are used in heavily loaded, low speed metal forming processes where liquid lubricants cannot provide adequate surface protection. Coatings of lead can function for the short times needed in rocket vehicles as solid film lubricants in sliding contact. Bores of gun tubes are plated with 93 Pb–7 Sn alloy to facilitate the passage of an oversized mandrel of tungsten carbide which induces residual stresses thereby raising the strength of the tube. Overlays of lead with additions of tin, indium, or tin plus copper are also used for bearing applications. Lead based overlays are superior to tin based overlays relative to fatigue strength. However, the reverse is true relative to superiority in erosion, corrosion and abrasion assistance. Lead coatings on high strength steels are effective in preventing hydrogen cracking in many different environments.

J. W. Dini, W. K. Kelley, W. C. Cowden, and E. M. Lopez, *Use of Electrodeposited Silver as an Aid in Solid State Bonding,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-88296 (1983). Prepared for the *Welding Journal.*

Sound, high strength solid state bonded joints were obtained with silver plated stainless steel, beryllium and uranium. The procedures used for preparing the substrates for plating were first characterized by using ring shear tests which provided quantitative information on bond adhesion. For the bonding studies, a full factorial experiment with two levels and four variables (2^4) was run with stainless steel. Fewer experiments were run with beryllium and uranium. Best joints were obtained with bonding conditions which included 1 hour at a temperature of 600°C, pressure of 30,000 psi and plating thickness of 6 mils of silver.

R. R. Donaldson and S. R. Patterson, *Design and Construction of a Large Vertical Axis Diamond Turning Machine,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89738 (1983). Prepared for the 27th Annual Intern. Techn. Symp. and Instrument Display, Soc. Photo-Optical Instrumentation Engineers, San Diego, CA, August 21–26, 1983.

A 64-in. swing, vertical spindle axis precision lathe has been constructed. The machine incorporates a multiple-path laser feedback system, capacitance gauges, a 32-bit computer and capstan drives to provide two axes of tool motion in a 32-in. radius by 20-in. length working volume. Dimensional stability of critical components is achieved through the use of low coefficient-of-thermal-expansion materials and temperature-controlled heat sinks. Projected accuracy of the machine is approximately one microinch rms.

E. D. Erikson, T. G. Beat, D. D. Berger, and B. A. Frazier, *Vacuum Outgassing of Various Materials,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89299 (1983). Prepared for the Vacuum Science & Techn., 30th National AVS Symp., American Vacuum Soc., Boston, MA, October 24–28, 1983.

A gas analytical system for measuring the evolved gases from materials during vacuum degassing is discussed. The outgassing data are based upon the throughput measurement, and a computer-controlled quadrupole mass spectrometer allows the determination of residual gas species. A variety of materials have been tested in the "as received" condition at room temperature vacuum exposure. Test results are presented for some unusual materials such as chlorinated polyvinyl chloride (CPVC), low-density carbon foam and Monel knitted wire mesh (both of which could be used for the attenuation of electromagnetic or radio frequency interference), polyethylene (in the form of black pipe, various thicknesses of sheet, or as an electrostatically applied coating to metal substrates) as well as Parylene-N conformal coatings applied to either CPVC, polyethylene, or stainless steel substrates.

B. Felker, M. O. Calderon, A. K. Chargin, F. E. Coffield, N. C. Gallagher, Jr., D. D. Lang, L. R. Pedrotti, R. R. Rubert, B. W. Stallard, D. W. Sweeney, and T. E. Christensen,* *Circular Waveguide Systems for Electron Cyclotron Resonant Heating (ECRH) for Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89235 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The ECRH system of rectangular waveguides on TMX-U has operated with a transmission efficiency of 50%. Each system uses a 28-GHz, 200-kW pulsed gyrotron. Four circular waveguide systems, with greater efficiency and power handling capabilities, have been designed and built to replace the retangular waveguides. Two of these systems, at the 5-kG second-harmonic heating locations, have a total transmission efficiency of 80%. The two systems at the 10-kG fundamental heating locations have a total transmission efficiency of 70%. The difference in efficiency is due to additional components required to launch the microwaves in the desired orientation and polarization with respect to magnetic field lines at the 10-kG points. These systems handle the total power available from each gyrotron without the arcing limitation problem of the rectangular waveguide. Several complex components are required for each system. A presentation of the overall physical layout and the design considerations for the four circular waveguide systems will be made.

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B. Felker, M. O. Calderon, A. K. Chargin, F. E. Coffield, D. D. Lang, R. R. Rubert, L. R. Pedrotti, B. W. Stallard, N. C. Gallagher, Jr., D. W. Sweeney, and T. E. Christensen,* *Design and Fabrication of Rectangular and Circular Waveguide Components for Electron Cyclotron Resonant Heating (ECRH) of the Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89234 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Extensive use of ECRH heating in TMX-U requires continuous development of components to improve efficiency, increase reliability, and deliver power to new locations with respect to the plasma. Rectangular waveguide components have been used on the experiment, and circular waveguide components have been developed and tested. The circular waveguide components will replace the rectangular ones because of their greater transmission efficiency and power-handling capability. Design, fabrication, and testing of mode filters, mode converters, arc detectors, corrugated bellows, bi-directional couplers, and vacuum windows have been complete for all systems. The circular systems require additional component fabrication and testing for vacuum valves and focusing polarizing mirrors. This paper describes the component criteria, design, and fabrication issues.

Donald C. Gerigk, *A High Accuracy Temperature Measurement on a Diagnostic Canister for the Nevada Test Site,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89191 (1983). Prepared for the Proc. 12th Transducer Workshop, Melbourne, FL, June 7–9, 1983.

A data system was designed to measure 30 temperatures to an overall accuracy of ±0.1°C. The temperature measurements were part of a dimensional stability study being done on a diagnostic canister used at the Nevada Test Site by the Lawrence Livermore National Laboratory. The system consisted of thermistors as the temperature-sensing element and a data logger which provided the following functions: current source, scanning system, voltmeter, and clock. A

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microprocessor, in turn, provided control to the data logger, a storage medium for the data, and the means for on-line conversion and display of the data. The performance of the system was optimized by calibrating each thermistor channel using the data system as readout and creating a unique calibration equation for each thermistor. Thus the system was calibrated as a whole to eliminate as many variables as possible. Four separate calibration runs were made. The data from one of these runs were used to calculate the constants for the temperature versus resistance equation for each thermistor channel. The data from the remaining three runs were then compared to resistance points calculated using this equation. The maximum deviation for any thermistor channel was 0.03°C. The system performed very well, recording data every hour for approximately three weeks.

D. A. Goerz, P. A. House, and C. W. Wells, *Design of the Plasma Current Sensor Diagnostic for MFTF-B*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89221 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The Plasma Current Sensors (PCS) include large diamagnetic loops (DL) that fully encircle the plasma as well as small multiturn pickup coils (PC) located between the plasma and the superconducting magnets. Both types of sensors respond to changing magnetic flux linkages caused by plasma currents and are used to measure plasma pressure (beta). The DLs are used in the center cell and Axicell regions, while the PCs are used in the Anchor regions where DLs were impractical. Eventually, other PCs will be used in the center cell to measure axial plasma currents. Although the sensors are simple in principle, the required measurement accuracies, 30-second shot length, and severe thermal environment inside the vessel provided challenging design constraints. This paper presents the design of the PCS diagnostic, and describes in detail the mechanical and electrical considerations.

A. Goldner, R. Stone, D. Humphries, P. Poulsen, J. Kerns, and M. Lane, *Design of a Magnet/Neutralizer to Limit Impurities and Nonprimary Species in MFTF-B*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89319 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Optimum plasma parameters for MFTF-B are very sensitive to heavy contaminates, such as oxygen and metals. It has been shown that the presently used neutral beam sources are not only a generator of high energy deuterium particles but also of high energy oxygen particles. The MFTF-B magnet/neutralizer is designed to filter out the unwanted oxygen and allow only primary species neutral to reach the plasma.

The magnet/neutralizer utilizes the concept of magnetic momentum separation of the various ionized energetic species. In most regions of MFTF-B (except the Passing Particle Barrier Beam, P2B2) the primary species is 80 keV neutral particles. Bending the 80 keV ions 6.9° with a separator magnet as they leave the source allows only these full energy particles to exit through a properly placed aperture. The oxygen ions and any particle with an atomic number greater than 2 are bent very little by the separator magnet and thus hit above the aperture. The half and third energy ions of deuterium are bent more than 6.9° and therefore hit below the aperture.

A parametric analysis has been done of the effect of varying the length of the neutralizer, length from the source to the magnet, and pressure distribution to optimize the system within the constraints imposed by MFTF-B. Also, an analysis of the separator magnet/species interaction has been completed to determine the trajectories of all the species of interest.

The prototype pure beam neutralizer will be tested in late 1983.

G. L. Goudreau, *Large Scale Computations*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89939 (1983). Prepared for the Workshop on the Theoretical Foundation of Large Scale Computations on Nonlinear Material Behavior, Northwestern University, Evanston, IL, October 24–26, 1983.

The central ingredients of general codes for large scale nonlinear material computation are reviewed as a focus and complement to other presentations on the theory and implementation of constitutive models. Spatial discretization by the simplest finite elements is discussed relative to integral differences and higher order finite element alternatives. Explicit and implicit transient integration strategies are evaluated. Contact sliding algorithms, rezoning, and vectorization are included as important aspects of large scale computing. A few examples are included.

G. L. Goudreau, *Stress Rates for Finite Deformation Lagrangian Analysis,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89182 (1983). Prepared as lecture notes for the ISPRA Courses on Structural Dynamics, Ispra Research Center, Ispra, Italy, May 16–20, 1983.

The issue of stress rates for finite deformation has both a theoretical and practical dimension. The rate formulation of finite deformation goes back to the "Non-Linear Field Theories" of Truesdell and Noll, and Naghdi's "General Theory of an Elastic-Plastic Continuum," but has mostly gathered dust until the modern computational codes have focused the underlying issues.

It has always been known that effective utilization of finite deformation mechanics would require an immense investment in the testing of real materials to enable the ambiguous potential of continuum constitutive theory. Unfortunately, most laboratory testing is limited to very specific applied goals, and material science research has been hampered by a) insufficient understanding of the general three dimensional theory of solid mechanics, b) insufficient multiaxial and variable stress path testing, and c) lack of computational tools to predict spatial, multiaxial, and temporal behavior of the experiment. However, rubber elasticity and metal plasticity have been two materials for which simple constitutive structure has been robust and have helped keep the issues under study. The first epitomizes the path independent material, illustrating hyperelasticity, the second the prototype of rate type constitutive theory (even if homogeneous in time), sometimes considered under the class of hypoelasticity.

It will be seen that the issue of stress rate, as in strain and strain rates, is one specific to the point wise constitutive problem, and not relevant to global or local discretization of momentum balance.

G. L. Goudreau, R. A. Bailey, J. O. Hallquist, R. C. Murray, and S. J. Sackett, *Efficient Large-Scale Finite Element Computations in a Cray Environment,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89385 (1983). Prepared for the 1983 ASME Winter Meeting, Boston, MA, November 14–18, 1983.

The Lawrence Livermore National Laboratory engineering computational experience on the CRAY-1 is highlighted in the context of our large general purpose solid and structural mechanics codes. DYNA2D and DYNA3D are explicit large deformation inelastic Lagrangian codes with one point elements and hourglass control. NIKE2D and NIKE3D are implicit codes of comparable continuum formulation but use two point constant pressure elements and an optimized linear equation solver. NIKE3D has a finite rotation plastic resultant shell element. The new general purpose linear elastic structures code GEMINI is also illustrated for large static and eigenvalue analysis.

G. L. Goudreau and J. O. Hallquist, *Selection and Optimization of Nonlinear Material Models for Lagrangian Continuum Computation,* Livermore National Laboratory, Livermore, CA, UCRL-88862 (1983). Prepared for the Symp. on Recent Developments in Computing Methods for Nonlinear Solid & Structural Mechanics, ASME Joint Meeting, University of Houston, TX, June 20–22, 1983.

A library of material models suitable for large Lagrangian continuum computation is presented in the context of the explicit DYNA and implicit NIKE finite element codes at the Lawrence Livermore National Laboratory. Both strain measures and material formulation are seen as a homogeneous stress point problem separate from field discretization and a flexible material subroutine interface admits both incremental and total strain formulation, dependent on internal energy or an arbitrary set of other internal variables. Our basic material library is reviewed including our latest selection for finite strain rate independent plasticity, hydrodynamic equations of state, and a new multisurface plasticity model. The emphasis is on integrating a selection of the models of others for variety and economy of material representation, as well as optimal programming for efficient computing.

J. O. Hallquist, *Bulk and Hourglass Viscosities in Wave Propagation Codes,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89156

(1983). Prepared as lecture notes for the Ispra Joint Research Center, Ispra, Italy, May 16–20, 1983.

Viscosities, bulk and hourglass, are employed in most finite element and finite difference wave propagation codes and serve two distinct, unrelated functions.

Bulk viscosities are used to treat shock waves. Proposed in one spatial dimension by von Neumann and Richtmyer in 1950, the bulk viscosity method has since been used by nearly all developers of wave propagation codes. A viscous term, q, added to the pressure, has the effect of smearing shock discontinuities into rapidly varying but continuous transition regions. With this method the solution is unperturbed away from shocks, the Hugoniot jump conditions remain valid across the shock transition, and shocks are automatically treated wherever they arise in the solution. In our discussion of bulk viscosity we draw heavily on works by Richtmyer and Morton, Noh, and Wilkins.

To economize on storage and maximize speed of execution, two and three dimensional wave codes usually under integrate the elements. Typically, one point integration is used per 4-node quadrilateral or 8-node hexahedron. As a result of this under integration, certain deformation modes can occur without generating strains. Hourglass viscosity, so named because of the characteristic hourglass patterns that occur in the mesh, resists these anomalous zero energy modes and has been used since the early sixties starting with HEMP and TENSOR. Although the orgin of the modes was not the subject of much discussion in the literature until later, its cause was well understood. In an attempt to avoid treating these modes, Johnson used triangular and tetrahedral elements, Key et al. made 2 × 2 integration optional in the second release of HONDO, and Hallquist for a short time period (1976–1978) attempted to use higher order elements.

To set the stage for the discussion of bulk viscosity which follows, we will first briefly discuss shock waves.

J. O. Hallquist, *Contact-Impact Algorithms for Large Deformation Finite Element Analysis,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89157 (1983). Prepared as lecture notes for the Ispra Joint Research Center, Ispra, Italy, May 16–20, 1983.

Finite element codes with contact-impact capability are applicable to a class of structural problems where adjacent components may independently slide, separate, and impact along interfaces. Problems of this sort are common in the defense community for analyzing axisymmetric gun fired projectiles, laydown bombs, and a variety of shape charge designs of either the jet or fragment type. The nuclear industry has interest in analyzing the impact of shipping casts containing radioactive materials, pipe to pipe impact, as well as soil-structure interaction problems. In the development that follows, we will consider three-dimensional algorithms. Similar techniques are employed in two dimensions. Several example applications are shown.

Contact-impact capability has always been an important aspect of the DYNA2D, DYNA3D, NIKE2D, and NIKE3D codes developed at the Lawrence Livermore National Laboratory. Nearly all our applications both explicit and implicit depend on it. Because these codes use nearly 1000 CPU hours of CRAY-1 time per year, we have been motivated to improve the algorithms on a continuous basis relying on ideas from the literature and our own research including a considerable amount of numerical experimentation. Today we can solve most contact-impact, finite strain, plasticity problems of interest to us with almost complete confidence that no numerical difficulties will arise.

Three distinct algorithms have been implemented which we will refer to as the:

- Nodal constraint
- Penalty
- Distributed parameter

methods. Of these, the first approach is now only used for tying interfaces in the DYNA codes. In this introduction, the merits of each approach will be discussed.

We define interfaces in two dimensions by specifying the string of nodes along each side of the interface. In three dimensions we list in arbitrary order all triangular and quadrilateral segments that comprise each side. One side of the interface is designated as the slave side, and the other is designated as the master side. Nodes lying in those surfaces are referred to as slave and master nodes, respectively. Due to the symmetry of the penalty method, this distinction is irrelevant. In the distributed parameter and nodal constraint methods the slave nodes are constrained to slide on the master surface after impact and to remain on the master surface until a tensile interface force develops.

M. A. Hamstad, *Aging Results for PRD 49 III/Epoxy and Kevlar 49/Epoxy Composite Pressure Vessels,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89919 (1983). Prepared for *Composites Technology Review.*

Kevlar 49/epoxy composite is growing in use as a structural material because of its high strengh-to-weight ratio. Currently, it is used for the Trident rocket motor case and for various pressure vessels on the Space Shuttle. In 1979, we published the initial results for aging of filament-wound cylindrical pressure vessels which were manufactured with preproduction Kevlar 49. This preproduction fiber was called PRD 49 III. This report updates the continuing study to 10-year data and also presents 7.5-year data for spherical pressure vessels wound with production Kevlar 49. For completeness, this report will again describe the specimens of the original study with PRD 49 as well as specimens for the new study with Kevlar 49.

M. A. Hamstad, S. H. Carpenter,* and A. A. Pollock,† *A Discussion of the Kaiser and Felicity Effects,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89167 (1983). Prepared for the Acoustic Emission Working Group Meeting, Princeton, NJ, June 25–29, 1983.

An introduction to the terms Kaiser and Felicity Effects as used in acoustic emission (AE) will be given. This will be followed by presentations on these effects in unflawed metals, flawed metals, and fiber composites. These presentations will discuss typical results, contradiction results, and mechanisms. Following the presentations a discussion will be held between speakers and the audience.

Hans J. Hansen, *Techniques for Precision Air Temperature Control,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89649 (1983). Prepared for the 27th Annual Intern. Techn. Symp. and Instrumentation Display, Society of Photo-Optical Instrument Engineers, San Diego, CA, August 21–26, 1983.

High quality air temperature control can provide an excellent means for minimizing the thermal drift of machine tools and inspection instruments when other means are not practical. Improvements in air temperature control have been made in several machining areas by as much as ten to one by the careful identification of heat loads and the application of some fundamental classical control theory.

C. L. Hanson, J. O. Myall, J. W. Wohlwend,* *Review of MFTF Ying-Yang Magnet Displacement and Magnetic Field Measurements and Calculations,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89259 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

During the recent testing of the MFTF yin-yang magnet, measurements of magnet position and magnetic field were made to verify calculated values. Measurements to detect magnet movement were taken throughout the cooldown and operation of the magnet. The largest displacements occurred when the magnet and the struts were cooled to cryogenic temperatures and when the yin-yang pair was powered to full current (5775 A). Calculations of magnet displacement and deflection were made by General Dynamics/Convair (GD/C) using beam element and beam plate computer models. The magnetic field at the mirror points were measured by Hall-effect probes. The magnet position and magnetic field measurements taken during the MFTF yin-yang testing indicate a reasonably close correlation with calculated values. Information obtained from the yin-yang test has been very useful in setting realistic mechanical alignment values for the new MFTF-B magnet system.

A. R. Harvey, *Construction Techniques for Short Iron-Free Dipole Magnets,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89271

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(1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Short iron-free dipole magnets used for steering particle beams transported in vacuum are defined as having an axial length to diameter ratio approaching 1.0. The constraints imposed on the configuration of these magnets were addressed in a paper presented at the 9th Symposium on Engineering Problems of Fusion Research. The conclusions drawn from this paper led to a proposed geometry in which the current elements at the axial ends of the dipole (non-productive elements) are placed in planes normal to the beam axis. This arrangement provides the maximum length of axial (productive) elements. To achieve a favorable impedance match for the power supplies and also to enhance the field uniformity, more turns than normally found in conventional steering magnets were proposed. The coupling of these two requirements imposes some unique fabrication difficulties. This paper addresses the design of these unconventional magnets from a construction point of view. Tooling, special forming, and encapsulating techniques are discussed. The production of 25 cross-dipole steering magnets for the Advanced Test Accelerator (ATA) at the Lawrence Livermore National Laboratory is used to illustrate the fabrication experiences encountered. Cost analysis, quality assurance, and procedural/tooling modifications currently under way are also discussed.

S. M. Hibbs, R. J. Kane, R. G. Kerr, and P. Poulsen, *Tandem Mirror Experiment Upgrade (TMX-U) Neutral Beam Test Stand: A Powerful Tool for Development and Quality Assurance,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89247 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

During construction of the TMX-U, we assembled a test stand to develop electronics for the neutral beam system. In the first six months of test stand use we operated a few neutral beam injector modules and directed considerable effort toward electronic system improvement. As system development progressed, our focus turned toward improvement of the injector modules themselves. Our experience has shown that the test stand is the largest single contributor to the successful operation of neutral beams on TMX-U, primarily because the test stand provides quality assurance and development capability in parallel with the scheduled activities of the main experiment. This support falls into five major categories: 1) electronics development, 2) operator training, 3) injector module testing and characterization, 4) injector module improvements, and 5) physics improvements (through areas affected by injector operation). Normal day-to-day operation of the test stand relates to category 3 and comprises our final quality assurance activity for newly asembled or repaired modules before they are installed on TMX-U. We have also used the test stand to perform a series of physics experiments. These evaluations include: gas flow reduction through valve and arc chamber characterization, impurity reduction by titanium gettering, and reduction of streaming gas using apertures and collisional gas dynamics. We discuss the test stand and show how unanticipated physics problems can be handled efficiently.

P. A. House, D. A. Goerz, and R. Martin, *Design of the Electromagnetic Fluctuations Diagnostic for MFTF-B,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89283 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The Electromagnetic Fluctuations (EMF) diagnostic will be used to monitor ion fluctuations which could be unstable in MFTF-B. Each probe assembly includes a high impedance electrostatic probe to measure potential fluctuations, and a group of nested, single turn loops to measure magnetic fluctuations in three directions. Eventually, more probes and loops will be added to each probe assembly for making more detailed measurements. The sensors must lie physically close to the plasma edge and are radially positionable. Also, probes at separate axial locations can be positioned to connect along the same magnetic field line. These probes are similar in concept to the RF probes used on TMX, but the high thermal load for 30 second shots on MFTF-B requires a more elaborate cooling scheme along with temperature monitors and interlocks. Each signal channel has a bandwidth of 0.001–100 MHz and is monitored by up to four different data channels which obtain amplitude and frequency information. Initially, there will be fewer data channels than signal channels with a patch panel arrangement for selecting configurations. The configuration is computer readable, while all other adjustable devices are remotely controlled. This paper presents the design of the EMF diagnostic, and describes in detail the mechanical and electrical considerations.

J. James,* S. H. Carpenter,* C. A. Tatro, M. A. Hamstad, and R. Vandervoort, *Investigation of the Acoustic Emission From Standard and Hydrogen Charged 304 Stainless Steel,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89375 (1983). Prepared for the Acoustic Emission Working Group Meeting, Princeton, NJ, June 26–29, 1983.

The acoustic emission generated during the deformation of 304 stainless steel in both standard and hydrogen charged conditions has been investiageted. Heat treatments and different chemical compositions have been used to produce different microstructures. Hydrogen charging produces significant effects on the mechanical properties but little effect on the acoustic emission. Little emission was observed in any condition, and that observed is believed due to the formation of ϵ-martensite.

R. J. Kane, S. M. Hibbs, R. G. Kerr, and P. Poulsen, *Organization and Performance of the Neutral Beam System for the Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89237 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The (TMX-U) at LLNL uses 24 neutral beam injectors to heat and fuel the experimental plasma. This system is unique in that TMX-U operates four times the number of injectors as any other fusion experiment. These injectors deliver an average of 50 A (accel) at 17 keV for 75 ms. Source conditioning time has been reduced to approximately four days for the entire system after extended machine air cycles. TMX-U is also unique in that it has 35 usable injector assemblies for the 24 power systems. This number of injectors allows the development of new hardware and injector modifications, as well as reconditioning of damaged sources without affecting on machine operation. Efficient operation of a system of this size requires coordinated interaction between the injector servicing groups and the physics organization. We describe the current state of TMX-U performance and emphasize the aspects of group interaction intrinsic to an activity of this size.

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W. K. Kelley, H. G. Patton, D. H. Fitch, B. L. Freitas, D. E. Hoffman, and E. M. Lopez, *Electropolishing Large Spatial Filter Tubes for the Novette and Nova High Energy Laser System,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89889 (1983). Prepared for *Plating and Surface Finishing.*

Procedures used for electropolishing the inner diameters of spatial filters, which are large stainless steel tubes used in the Novette and Nova high energy laser systems, are described. These parts, which are as large as 74-cm diameter and 792-cm long, were impractical to electropolish in open tanks. Therefore, they were mounted horizontally and rotated. Details are presented on how the electropolishing was accomplished.

J. Kerns, A. De LaPaz, and J. Fabyan, *Magnetic Shielding Design Analysis,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89318 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Magnetic shielding design is usually performed using equations for spheres or infinite cylinders. Complicated shapes have been approximated using shielding relations for an ellipsoid of revolution. The first section of this paper will review these shielding calculations along with end effects of finite cylinders in transverse and axial fields.

Another approach to shielding design is to calculate the magnetic flux entering the shield, then calculate the field inside the metal, and finally use a Hystersis curve to determine the internal field. This technique is accurate and independent of shape but the external magnetic field must be known. This external field can be calculated using codes like GFUN or TOSCA, but this could lead to an excessive amount of work for initial or interim designs.

An estimate to the magnitude of the external fields can be made based on experimental data taken at LLNL. The experimental results came from one-tenth scale model tests of neutral beamline shields and from testing simple shapes in a uniform magnetic field. The experimental tests and results will be presented in the paper.

The test results are then used to develop an approximation to the external fields around a shielding design. This approximation can be useful in future shielding design work for neutral beamlines or other devices attached to magnetically confined fusion machines.

J. Kerns, J. Fabyan, R. Wood, and P. Koger, *Magnetic Shielding Tests for MFTF-B Neutral Beamlines,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89321 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

A test program to determine the magnetic shielding effectiveness of various shielding designs for MFTF-B beamlines has been established at Lawrence Livermore National Laboratory (LLNL). The proposed shielding designs are reduced to one-tenth scale models and tested in a uniform field produced by a Helmholtz coil pair. A similiar technique was tried and proven for the MFTF source-injector assemblies and the results of the model tests were confirmed during the Technology Demonstration in 1982.

The one-tenth scale models which were tested included various combinations of source-injector, iron bending magnet, and finger assembly. The tests were conducted at various field incident angles to the model along with different field levels. It was assumed that if the model performed well at a uniform field level, which equaled the maximum field the actual beamline would see, then the shielding design would be adequate. The Doublet III shielding design was also tested to see if this design could be adapted to MFTF-B.

The test results show that both the LLNL and Doublet III designs are good designs for transverse fields, but both designs were poor for the axial field case. Test results show that axial fields of 400 gauss saturate the shield and would alter the source operation. The best shield for axial fields was the source-injector assembly tested by itself.

The results of these tests have impacted the beamline design for MFTF-B. The iron core magnet and finger assembly originally proposed have been deleted for a simple air core racetrack coil bending magnet. Only the source injector is magnetically shielded and a bucking coil will be used on the beamlines which will see axial fringe fields of 400 gauss.

R. P. Kershaw, R. J. Gross, and E. N. C. Dalder, *Failure Analysis of Ti-15% Ta Getter Wire Used for Sublimation in the Vacuum Chambers of the Tandem Mirror Experiment,* Lawrence Livermore National Laboratory, Livermore, CA, UCID-19898 (1983).

The Tandem Mirror Experiment uses Ti-15% Ta getter wire for sublimation in the vacuum chambers in which the magnets are located. These wires have failed prematurely in service, resulting in increased costs and downtime.

We have used optical metallography to show that the reason for these failures was the cycling of the material through the alpha-beta transition temperature, causing alpha-titanium precipitation at the grain boundaries, depression of the melting temperatures of those boundaries, and the subsequent melting of those boundaries in areas where the wires had achieved localized higher temperatures.

R. J. King and P. Stiles, *Microwave Nondestructive Evaluation of Composites,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89922 (1983). Prepared for the Proc. of the Review of Progress in Quantitative NDE Conf., University of California, Santa Cruz, August 7–12, 1983.

New reliable and sensitive nondestructive evaluation (NDE) techniques are demanded for quality control, safety, liability and economic reasons. They are essential for measuring defects such as foreign material, voids and cracks, and for measuring changes in material characteristics such as hardness, specific gravity, moisture content, aging effects, composition, thickness, and in the case of anisotropic media, axis alignment, e.g., grain angle. Microwave techniques are rapidly becoming viable tools for nondestructive testing of semiconducting materials (composites, plastics, wood, rubber, etc.), especially when ultrasonic and x-ray methods are limited.

This paper focuses on the use of microwaves to measure the presence of minute amounts of diffused moisture in dielectric materials of which composites are but one example. The presence of such moisture is thought to be a diagnostic indicator of the structural integrity and aging of composites. The chief objective here is to demonstrate the feasibility of using an open-ended coaxial resonator to monitor moisture. The results reported here are preliminary in that they are not quantified to any degree of accuracy, but merely show the trends observed so far. More quantified results will be reported as this work progresses.

Marvin K. Kong, Carl E. Walter, and Howard H. Woo, *Mechanical Analysis of a Transportation Accident Involving Empty Shipping Casks for Radioactive Materials Near Hilda, South Carolina, in November 1982,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53484 (1983). Prepared for the U.S. Nuclear Regulatory Commission, Washington, DC, NUREG/CR-3452.

Any accident involving a passenger automobile and a tractor-trailer carrying two empty shipping casks for transporting low-level radioactive materials occurred on November 3, 1982, near Hilda, SC. The purpose of this report is to document the mechanical circumstances of the accident, and to assess the types and magnitudes of accident environments to which the casks were subjected.

The report contains two major parts. The first concerns the accident description, which includes fact-finding and the inferred accident scenario. The second part deals with the mechanical analysis of the accident, consisting of estimates of the impact loads and an assessment of the response of the casks and their tie-down systems. Discussions of results and recommendations are also included.

M. Lane, *SPAN: A Computer Program to Analyze Two-Phase Natural Convection Helium Flow Through the MFTF-B Cryopanel System,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89317 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The MFTF-B cryopanel system has been analyzed in order to ensure system stability when transient heat loads are applied during MFTF-B experimentation. Helium will travel through the system on the same time scale as the heating pulse, therefore it cannot be analyzed as a pseudo-steady-state condition.

The cryopanel system consists of two liquid helium supply dewars and cryogenic piping which feed 1000 m^2 of cryopanel surface in two separate flow loops. This high vacuum system occupies portions of the east and west end vessels of the Mirror Fusion Test Facility (MFTF-B) and is maintained at 4.35 K. The liquid helium flow is driven by natural convection. In addition to the steady-state heat load (max. 2600 W), there are pulsed heat loads on the cryopanels of up to 4500 W. Data from SPAN will be used to size microwave absorbers for MFTF-B.

The governing transient equations for two-phase helium flow were written assuming that homogeneous flow exists in the cryopanel system. The resultant coupled nonlinear partial differential equations were solved numerically by PDECOL, a computer software package able to handle the unusual initial condition that the mass flow rate is unknown throughout the system.

A quantitative check of the transient equations was made by modeling the Technology Demonstration helium flow configuration and comparing results to experimental data where adequate circulation was known to occur. Then the MFTF-B helium piping for the cryopanels was modeled. Parameters such as geometry and heat load distribution were easily varied in SPAN when needed. The cryopanel system has thus been designed so that the quality of the two-phase helium does not exceed 5% anywhere in the flow loop for the given design heat loads. SPAN has increased the understanding of the helium flow through the MFTF-B cryopanel system, and is useful in modeling other transient two-phase flow situations.

D. D. Lang, M. O. Calderon, A. Hunt, W. E. Nexsen, W. L. Pickles, and W. C. Turner, *Tandem Mirror Experiment Upgrade (TMX-U) Vacuum System—A New Configuration and Operating Parameters,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89248 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The TMX-U vacuum system has been operating since December 1981. The external high vacuum system consists of two turbomolecular pumps and six refrigerated cryopumps that together evacuate the 212-m^3 vessel. The fast internal pumping system uses titanium gettering on liquid-nitrogen-cooled panels. Internal pumping regions have recently been reconfigured to limit the conductance between them by replacing apertures with short duct sections and by reducing the open area of the remaining apertures. We will discuss this new design and the operating performance of the external and internal pumping systems. Typical pumpdown sequences, including external pumping system performance, leak checking, baking, and glow discharge cleaning (with the total rate of rise measured at each step), will also be presented. In addition, we will refer to the performance of the internal pumping system during a plasma shot as well as with the measured titanium gettering pumping speeds and saturation point limits. The external vacuum system obtains pressures of 3×10^{-6} Torr without titanium gettering or liquid nitrogen panels. With the addition of the internal pumping system, base pressures below 2×10^{-8} Torr are produced.

T. Lo, H. H. Woo, G. S. Holman, and C. K. Chou, *Probabilistic Assessment of PWR Reactor Coolant Loop Piping,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86249 (1983). Prepared for the ASME Advances in Probabilistic Structural Mechanics, San Antonio, TX, June 17–21, 1984.

In nuclear power plant design, postulation of a double-ended guillotine break (DEGB) in the primary coolant piping introduces severe design problems. They include: asymmetric blowdown; pipe whip restraints; and SSE plus DEGB load combination. The U.S. Nuclear Regulatory Commission (NRC) has contracted the Lawrence Livermore National Laboratory (LLNL) to conduct a probabilistic assessment of the primary coolant piping of all existing nuclear power plants. It was hoped that the results of the assessment would indicate that the probability of occurrence of both direct and indirect DEGB would be small enough to safely eliminate the postulation of DEGB in the design requirements. The assessment has been divided into two parts: DEGB due to direct crack growth of existing flaws in the piping; and DEGB indirectly induced by sources other than flaws, such as the failure of component supports.

This paper describes the results of the assessment performed on the reactor coolant loop piping of Westinghouse and Combustion Engineering plants. For direct DEGB, consideration was given to crack existence probability, hydrostatic proof test, pre-service inspection, in-service inspection, leak detection probability, crack growth characteristics, and failure criteria based on net section stress failure and tearing modulus stability concept. For indirect DEGB, fragilities of major component supports were estimated. The system level fragility was developed by calculating the boolean expression involving these fragilities. Indirect DEGB due to seismic effects was calculated by convolving the system level fragility and the seismic hazard curve. The results indicated that the probability of occurrence of both direct and indirect DEGB is extremely small, thus postulation of DEGB in design should be eliminated and replaced by a more realistic criteria.

Stephen C. Lu, *Reliability Analysis for Stiff Versus Flexible Piping,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86246 (1983). Prepared for the 11th Water Reactor Safety Research Information Meeting, Washington, DC, October 24–28, 1983.

A confirmatory piping reliability assessment for stiff versus flexible piping systems indicated that removing rigid supports tends, in general, to reduce thermal stress but to increase seismic stress in the pipe. As a result, piping design can be made more reliable by some reduction of rigid supports. We also observed that piping design using snubbers among support devices may not exhibit the intended reliability because snubbers often fail to perform the desired function. It was demonstrated that certain piping systems with snubbers removed actually exhibit higher reliability than do those of the original design.

The Steering and Technical Committees on Piping Systems established by the Pressure Vessel Research Committee (PVRC) has investigated changes to be implemented in Regulatory Guide (RG) 1.61 and RG 1.122 aimed at more flexible piping design. An independent impact assessment conducted by this project concluded that:

1. PVRC-proposed changes substantially reduce calculated piping responses.

2. Calculated responses exhibit sufficient safety margins when compared with probabilistic time-history results.

3. Proposed changes allow piping redesigns with significant reduction in number of supports

and snubbers without violating ASME code requirements.

4. The more flexible piping redesigns are capable of exhibiting reliability levels equal to or higher than the original stiffer design.

B. W. Maxfield and H. H. Woo, *Simulation of Loading Conditions for a Type A Package Containing Americium-241 Involved in an Airplane Crash at Detroit Metro Airport in January 1983,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53492 (1983). Prepared for the Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC, NUREG/CR-3536.

On January 11, 1983, a United Airlines DC-8F cargo aircraft crashed shortly after takeoff from Detroit Metro Airport. A lower rear cargo pit had a type A package containing 10,000, Americium-241 (^{241}Am) solid-form sources, each of 1.5-microcurie (μCi) strength, used in smoke detectors. Although burned and somewhat battered, the 1-gal metal can holding all these sources was recovered completely intact with no release of radioactive material to the environment or loss of any sources. This report describes Lawrence Livermore National Laboratory's attempt to reconstruct, as closely as practical, the mechanical and thermal environments experienced by this can during and immediately after the accident. Mechanical loading of the metal can in a shipping carton was simulated by impacts from a 16-lb pendulum mass falling through vertical displacements of up to 6 ft. Internal damage ranged from imperceptible to sufficient to demolish internal plastic jars and to produce major deformation of the metal can. The thermal environment was best reproduced by the simple burning of the outer shipping carton.

A. J. McAlice, T. L. Moore, D. D. Lang, and R. E. Pico, *Computer Control of the Titanium Getter System on the Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89245 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Gettering has been a standard technique for achieving high quality vacuum in fusion experiments for some time. On Lawrence Livermore National Laboratory's TMX-U, an extensive gettering system is utilized with liquid-nitrogen-cooled panels to provide the fast pumping during each physics experiment. The getter wires are an 85% titanium 15% tantalum alloy directly heated by an electrical current. TMX-U has 162 getter power-supply channels; each channel supplies approximately 106 A of regulated power to each getter for a 60-s cycle. In the vacuum vessel, the getter wires are organized into "poles" or arrays. On each pole there are six getter wires, each cabled to the exterior of the vessel. This arrangement allows the power supplies to be switched from getter wire to getter wire as the individual wires deteriorate after 200 to 300 gettering cycles, effectively regettering the system without raising the vessel to atmospheric pressure for maintenance. To control the getter power supplies, we will install a computer system to operate the system and document the performance of each getter circuit. This computer system will control the 162 power supplies via a Computer Automated Measurement and Control (CAMAC) architecture with a fiber-optic serial highway. Getter wire history will be stored on the built-in 10MB disc drive with new entries backed up daily on a floppy disc. Overall, this system will allow positive tracking of getter wire condition, document the total gettering performance, and predict getter maintenance/change over cycles. How we will employ the computer system to enhance the getter system is the subject of this paper.

Howard K. McCue, *The Motion Control System for the Large Optics Diamond Turning Machine (LODTM),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89362 (1983). Prepared for the SPIE's 27th Annual International Technical Symposium and Instrument Display, San Diego, CA, August 21–26, 1983.

LODTM, built by LLNL for DOD, is a precision vertical lathe used to diamond turn large optical parts (to 64-in.-diam) to 1-μinch rms figure error. The LODTM motion controls require precision sensors, precision servos, and a wideband (330 Hz) real-time computer. Position is sensed to 1/40-μinch resolution by laser interferometers and differential capacitance gauges. Precision servos operating at 1/10-μinch resolution and at low velocities with zero backlash are required. A unique

Fast Tool Servo (FTS), located close to the diamond tool, adjusts the final tool position. The LODTM controls coordinate the X, Z, and FTS servos to cause the tool to move on a specified contour and at a specified feedrate in the X-Z plane. The part floppy diskette commands this motion with a linear CNC and real time (32-bit) computer. During each 1.5-ms sample time, the computer must DMA 14 sensor readings into memory, calculate the X and Z Tool Coordinates, calculate the FTS input, output the following errors, output the FTS input, store "flight recorder" information, and check for anomalies.

Ronald L. McKinney, Don Boyd, Aki Kuramoto, and Bill McDonald, *Signal Processing Capabilities of a Computerized Ultrasonic Scanning Bridge,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89341 (1983). Prepared for the Automated NDE Conf., Idaho Falls, ID, June 28–30, 1983.

Digital signal processing techniques have been implemented using a computerized ultrasonic scanning bridge. Signals are processed in A-Scan, B-Scan, and C-Scan mode. In A-Scan mode general arithmetic and transform techniques such as addition, subtraction, multiplication, division, differentiation, integration, fourier transforms, and calculated functions are utilized. B-Scan mode signal processing options are analytic function, split spectrum processing, frequency domain windowing and spatial averaging. In C-Scan mode available manipulations are addition, subtraction, multiplication, division, inversion, high and low pass filtering and edge enhancement. A-Scans and B-Scans are processed using an array processor and a DEC (Digital Equipment Corp.) LSI 11/23 computer. C-Scan images are processed using a Peritek VC6-512Q graphics display board. Results have proved favorable both in processing time and in additional information provided by the techniques.

William H. McMaster, *Fluid-Structure Interactions,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89724 (1983). Prepared for the Symp. in Recent Advances in Fluid-Structure Advances Interaction, 1983 Pressure Vessel and Piping Conf., San Antonio, TX, June 1984

Three Eulerian finite difference fluid dynamics codes are available for the analysis of fluid-structure interactions where the fluid motion is drastic enough to cause difficulties in the Lagrangian formulation. These codes are

PELE-IC An implicit incompressible two dimensional fluid coupled to a thin shell finite element code,

PELE3D An implicit incompressible three dimensional fluid coupled to a structure, and

MAUI An explicit compressible two dimensional fluid coupled to a structure.

William H. McMaster and J. O. Hallquist, *Fluid-Structure Coupling of Compressible Materials,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89323 (1983). Prepared for the Intern. Conf. on Numerical Methods for Transient & Coupled Problems, Venice, Italy, July 9–13, 1984.

An algorithm has been developed for the analysis of the fluid-structure interaction between compressible materials and moving structures. This algorithm has been implemented within a two-dimensional Eulerian hydrodynamics computer program, MAUI, which computes the flow of the compressible materials with free surfaces and provides the coupling to the Lagrangian structures-hydrodynamics code, DYNA2D. The solution of the conservation equations of mass, momentum, and energy is accomplished using the two-step method of solving the Lagrangian part first followed by an Eulerian re-map which allows multiple material motion through a fixed grid. The MAUI code uses finite differences for the discretization of the fluid and the DYNA2D code uses finite elements to characterize the structure.

This fluid-structure coupling algorithm is general enough to handle a wide variety of structural shapes and will allow the structure to move freely through the grid containing the compressible materials. The interface between the two is maintained by a Lagrangian boundary defined by a series of sequential nodal points. In the calculations, the material pressure field is used by the Lagrangian code to determine the structural response and the structure's subsequent position and velocity are used by the Eulerian code to determine the material coupling.

Peter B. Mohr and Carl E. Walter, *Flywheel Rotor and Containment Technology Development—FY83,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-86557-83 (1983). Prepared for the DOE Physical & Chemical Energy Storage Annual Contractors Review Meeting, Arlington, VA, September 12, 1983.

The Department of Energy decided to terminate the Flywheel Rotor and Containment Technology Development project during FY 1983. Activities this year included fabrication, inspection, and test evaluation of rotor and containment structures. A peak energy of 700 Wh was stored at an energy density of 70 Wh/kg. In cyclic tests, 10,000 cycles from design speed to half speed were logged without failure. The first test of a lightweight containment structure indicates the need for additional development. In complementary studies, production cost estimates were made for three flywheel designs. In a cooperative program with the University of Wisconsin, work began on construction of a flywheel/continuously variable transmission/heat engine car which promises fuel economy improvements of up to 100%.

Suggestions are made for the direction of future work when interest in flywheel system reappears.

T. L. Moore, W. F. Cummins, A. L. Henderson, P. G. Karsner, A. W. Molvik, L. R. Pedrotti, and D. W. Scofield, *Ion Cyclotron Radio Frequency (ICRF) Systems and Performances on Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89240 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The use of ICRF to heat plasma has received much attention in recent years. At LLNL's TMX-U, we use two antenna designs to operate in the 1 to 20 MHz range with radio frequency (rf) power level to several hundred kilowatts. The first design is a loop-type antenna, subtending 110 degrees of arc. It has five turns in the loop to allow operation as low as 1.6 MHz with 1600-pf tuning capacitors. The loading resistance is less than 0.1 ohm for launching slow waves. The second design antenna is a "slot" antenna that provides a higher plasma loading resistance of approximately 0.5 ohm with slow waves, and applies rf fields uniformly across the plasma cross section. TMX-U incorporates real-time impedance measurement techniques in which the transmitters and network analyzer are configured in a phase-locked measurement apparatus. This allows electrical characterization of the antenna with plasma loading. Using the information provided by the analyzer, we can tune the antenna with "windage" such that, in the presence of plasma, the antenna provides a suitable load to the transmitter. A summary discussion of the physics issues addressed by these antennas is available.

D. S. Ng, *Static and Dynamic Analyses on the MFTF-B Vacuum Vessel,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89316 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The Mirror Fusion Test Facility (MFTF) is one of the magnetic fusion energy projects at the Lawrence Livermore National Laboratory. The engineering objective of this program is to design and build a mirror fusion test facility. The experiment is designed to create a fusion reaction by injecting beams of energetic neutral atoms into a high temperature plasma confined by a magnetic field in a vacuum chamber. One of the major components of this fusion test facility is the vacuum vessel which forms the vacuum chamber. The magnetic field is generated by groups of superconducting magnets supported inside the vessel by hangers and struts. The vessel is supported on 22 pairs of legs resting on reinforced concrete piers. This paper is a report of the static and dynamic analyses on the vacuum vessel including hangers and magnets.

During the experiment the superconducting magnets will be maintained at the cryogenic temperature of 4 K while the vessel remains at room temperature. The differential temperature creates thermal loading in the hangers. Additionally after energization the magnets generate electromagnetic forces which will be transmitted to the vessel. In our analyses we investigated the load distribution under the gravity loads, the pressure loads, the electromagnetic loads and the thermal loads separately. We also performed a series of sophisticated dynamic analyses to predict the structure behavior under postulated earthquake. The modeling assumptions and analysis procedures are highlighted in the presentation. The static deformed shape and dynamic mode shapes will be simulated by a computer-generated movie.

L. R. Pedrotti and R. L. Wong, *Tandem Mirror Experiment Upgrade (TMX-U) Throttle, Mechanical Design, Construction, Installation, and Alignment,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89239 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

We have added a high-field axisymmetric throttle region to the central cell of the TMX-U. Field amplitude can now be adjusted to between 2.25 and 6.0 T. This field is produced by adding a high-field solenoid and a reverse cee coil to each end of the central cell. We describe these coils as well as the additions to the restraint structure. We analyzed the stresses within the solenoid using the STANSOL code. In addition, we performed a finite-element structural analysis of the complete magnet set with the SAP IV code. Particular attention was paid to the transition section where the new magnets were added and where the currents in the existing magnets were increased. The peak temperature rise in the throttle coil was calculated to be +41°C above ambient. This is the peak temperature used in all pulsed water-cooled coils. We verified the validity of the initial hand calculation using a finite-difference computer model.

John H. Pitts, *Mechanical and Thermal Design of the Cascade Reactor,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89273 (1983). Prepared for the 10th Symposium on Fusion Engineering, Philadelphia, PA, December 5–9, 1983.

We present an improved Cascade fusion reaction chamber that is optimized with respect to chamber radius, wall thickness, and pebble blanket outlet temperature. We show results of a parameter study where we varied chamber radius from 3 to 6 m, wall thickness from 15 to 80 mm, and blanket outlet temperature from 900 to 1400 K. Based on these studies, we achieved an optimized chamber with 50% the volume of the original design and 60% of its blanket. Chamber radius is only 4.4 m and its half length is only 5.9 m, decreased from the original 5-m radius and 8-m half-length.

In our optimization method, we calculate both thermal and mechanical stresses resulting from x-ray, fusion-pellet-debris, and neutron-generated momentum, pressure from ablated material, centrifugal action, vacuum inside the chamber, and gravity. We add the mechanical stresses to thermal stresses and keep the total less than the yield stress. Further, we require that fluctuations in these stresses be less than that which would produce creep-fatigue failure within the chamber 30-year lifetime.

J. W. Roblee, D. W. Stillman, and S. R. Patterson, *Precision Support of Annular Optics,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89756 (1983). Prepared for the 27th Annual Intern. Techn. Symp. and Instrumentation Display, Society of Photo-Optical Instrumentation Engineers, San Diego, CA, August 21–26, 1983.

A quantitative description of the deformation of an annular optical element subject to external forces has been developed. Expressions applicable when the width of the element is small compared to its radius provide distortion data for both free rings and rings supported on thin-wall cylinder segments ("tangent flanges"). This data may be used to guide the design of fixtures for diamond turning large annular optics.

R. R. Rubert, F. E. Coffield, B. Felker, B. W. Stallard, J. Taska, and C. W. Williams, *Microwave Measurement Test Results of Circular Waveguide Components for Electron Cyclotron Resonant Heating (ECRH) of the Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89242 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Development of high power components for ECRH applications requires extensive testing. In this paper we describe the high-power testing of various circular waveguide components designed for application on the TMX-U. These include a 2.5-inch vacuum valve, polarizing mirrors, directional couplers, mode converters, and flexible waveguides. All of these components were tested to 200 kW power level with 40-ms pulses. Cold tests were used to determine field distribution. The techniques used in these tests will be illustrated. The new high-power test facility at LLNL is described and test procedures discussed. The test results include efficiency at high power of mode converters, comparison of high power vs low power for waveguide components, and full power tests of the antenna system. The test results from the systems chosen to support TMX-U are described, as well as the reasons behind these selections.

R. R. Rubert, B. Felker, B. W. Stallard, and C. W. Williams, *Fundamental Mode Rectangular Waveguide System for Electron Cyclotron Resonant Heating (ECRH) for Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89241 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

We present a brief history of TMX-U's ECRH progress. We emphasize the 2-year performance of the system, which is composed of four 200-kW pulsed gyrotrons operated at 28 GHz. This system uses WR42 waveguide inside the vacuum vessel, and includes barrier windows, twists, elbows, and antennas, as well as custom-formed waveguides. Outside the TMX-U vessel are directional couplers, detectors elbows, and waveguide bends in WR42 rectangular waveguide. An arc detector, mode filter, eight-arm mode converter, and water load in the 2.5-inch circular waveguide are attached directly to the gyrotron. Other specific areas discussed include the operational performance of the TMX-U pulsed gyrotrons, windows and component arcing, alignment, mode generation, and extreme temperature variations. Solutions for a number of these problems are described.

E. W. Russell, R. D. McCright, and W. C. O'Neal, *Containment Barrier Metals for High-Level Waste Packages in a Tuff Repository,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53449 (1983).

The Nevada Nuclear Waste Storage Investigations (NNWSI) Waste Package project is part of the U.S. Department of Energy's Civilian Radioactive Waste Management (CRWM) Program. The NNWSI project is working towards the development of multibarriered packages for the disposal of spent fuel and high-level waste in tuff in the unsaturated zone at Yucca Mountain at the Nevada Test Site (NTS). The final engineered barrier system design may be composed of a waste form, canister, overpack, borehole liner, packing, and the near field host rock, or some combination thereof. Lawrence Livermore National Laboratory's (LLNL) role is to design, model, and test the waste package subsystem for the tuff repository.

At the present stage of development of the nuclear waste management program at LLNL, the detailed requirements for the waste package design are not yet firmly established. In spite of these uncertainties as to the detailed package requirements, we have begun the conceptual design stage. By conceptual design, we mean design based on our best assessment of present and future regulatory requirements. We anticipate that changes will occur as the detailed requirements for waste package design are finalized.

E. W. Russell, R. D. McCright, and W. C. O'Neal, *Selection of Barrier Metals for a Waste Package in Tuff,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89404 Rev. 1 (1983).

The Nevada Nuclear Waste Storage Investigations (NNWSI) project under the Civilian Radioactive Waste Management Progam is planning a repository at Yucca Mountain at the Nevada Test Site for isolation of high-level nuclear waste. Lawrence Livermore National Laboratory is developing designs for an engineered barrier system containing several barriers such as the waste form, a canister and/or an overpack, packing, and near field host rock. In this papaer we address the selection of metal containment barriers.

M. L. Scott* and W. E. Alston, *High Angle of Incidence Anti-Reflection Coatings for Use in Dye Laser Cavity Optics,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-88219 (1983). Prepared for the Los Alamos National Laboratory Conf. on Optics '83, Santa Fe, NM, April 11, 1983.

The gain region in a tunable dye laser cavity is typically quite small and, therefore, the beam emerging from this region has a small diameter. In order to make effective use of a wavelength selective element such as a Littrow mounted diffraction grating in such a cavity, a beam expander is required. The use of prisms in this beam expander

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requires a high angle of incidence at some interfaces. Anti-reflection coatings of TiO_2 and SiO_2 were designed and fabricated on fused quartz (75°) and BK-7 glass (83.1°) substrates. Both coatings were designed to select p polarization in the dye cavity.

J. F. Shackelford,* *University of California Participation in the CIRP Round Robin of Residual Stress Measurement*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19838 (1983).

The University of California, Davis, in conjunction with the Lawrence Livermore National Laboratory has participated in an international round robin testing program for residual stress measurement by x-ray diffraction. The comparative results among five participating laboratories were quite good with scatter in the data being less than ±10%.

Arthur B. Shapiro, *Computer Implementation, Accuracy and Timing of Radiation View Factor Algorithms*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89602 (1983). Prepared for the 1983 ASME Winter Meeting, Boston, MA, November 14–18, 1983.

The three-dimensional finite element thermal analysis of enclosure radiation problems requires the calculation of the geometric surface to surface radiation view factors. The view factors can be calculated by either area or line integration algorithms. This paper addresses the implementation, accuracy and computational time involved in using these algorithms. Additionally, an algorithm to identify shadowing surfaces and methods to adjust the calculated view factors for increased accuracy are presented.

R. Stone and T. Duffy, *Optimized Baffle and Aperture Placement in Neutral Beamlines*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89320 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Most neutral beamlines have an iron core ion bending magnet and shielding between this magnet and the end of the neutralizer. The purpose of the shielding is to allow the gas pressure to drop prior to the neutrals entering the magnet. The shielding eliminates the beam losses in this drift region. Under certain conditions, the beam losses can be reduced by eliminating the iron core magnet and the magnetic shielding altogether. The required bending field can be supplied with current coils without the iron poles. The beam losses in such a system can be less than or equal to that in a beamline with the usual shielding configuration.

The placement of the baffles and apertures can have a large effect upon the gas entering the plasma region and the losses in the neutral beam due to reionization. With a given pumping capacity and beamline length, this paper shows the results of varying the placement of baffles, and therefore, the amount of pumping in each chamber, and the location of apertures. It can be shown that the baffle/aperture configuration can be set for either minimum cold gas into the plasma region or minimum beam losses, but not both. The effect of such a study allowed the elimination of one baffle and aperture set on MFTF-B with a corresponding costs savings.

George P. Sutton, *An Introduction to Flexible Manufacturing Systems: Their Applications, Classification, and Opportunities*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89746 (1983). Prepared for the FMS-WEST Seminar, Anaheim, CA, September 20–22, 1983.

A flexible manufacturing system (FMS) is a set of co-located, automatic, computer-numerical controlled machine tools with a common material handling subsystem and a common supervisory computer, aimed at randomly producing a series of parts or fabricated components, which has a family resemblance. The flexibility to produce different parts in varying quantities and in a random sequence allows economies in the fabrication cost, lead time, and in-process inventory; these economies would not be achievable if these same parts would have to be produced on separate conventional fabrication machinery.

This paper introduces the subject of FMS, its classifications, applications, major subsystems or components, user benefits, and market opportunities.

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Clement A. Tatro and Alfred Goldberg, *Characterization of Martensitic Transformations Using Acoustic Emission,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89374 (1983). Prepared for the Acoustic Emission Working Group Meeting, Princeton, NJ, June 26–29, 1983.

Three steels which form distinctly different martensites are being studied. We hope to better define the acoustic emission response from martensitic transformations as a function of heat treatment, material composition, and residual stress state. The investigation is in progress.

P. L. Tassano, *Deposition of Cesium Iodide on Parylene,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89776 (1983). Prepared for the Intern. Nuclear Target Development Soc., Eastsound, WA, September 7–10, 1983.

This paper describes a technique we developed for coating thin Parylene with thin films of cesium iodide and presents results obtained in a comparative evaluation of these films with commercially produced films.

S. T. Wang, T. A. Kozman, R. Bulmer, C. L. Hanson, R. E. Hinkle, D. W. Shimer, J. H. Van Sant, J. O. Myall, E. W. Owen, G. Yamaguchi, B. Johnston, K. Z. Tipton, G. Lathrop, and R. Patrick, *Progress on Axicell MFTF-B Superconducting Magnet Systems,* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89260 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

Since the entire MFTF-B Magnet System was reconfigured from the original A-cell to an axicell design, a great deal of progress has been made on the design, the fabrication, the verification test and the installation. The axicell MFTF-B magnet array consists of a total of 26 large cryostable superconducting coils: 2 sets of yin-yang pairs, 2 sets of axicell magnets (each containing three coils), 2 sets of transition coils (each containing two coils) and 12 central cell solenoids. This paper outlines the design requirements first, then it provides an engineering overview on progress in the design, the fabrication, the verification test and the installation efforts.

Recent studies on the effects of field errors on the plasma at the recircularizing region (transition coils) showed that small field errors will generate large displacements on the field lines. These field errors might enhance radial electron heat transport and deteriorate the plasma confinement. Furthermore, it might result in incorrect aiming of neutral beams and incorrect location of plasma diagnostics. Therefore, a total of 16 superconducting trim coils are being designed and fabricated to correct the coil misalignments. Progress in the trim coils system will also be reported.

R. L. Wong, *Magnetic Design of the Axisymmetric Throttle Coil Addition to the Tandem Mirror Experiment Upgrade (TMX-U),* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-89243 (1983). Prepared for the 10th Symp. on Fusion Engineering Problems, Philadelphia, PA, December 5–9, 1983.

The TMX-U magnet set is shown in detail, including modifications with the addition of axisymmetric throttle coils and fan reversing transition magnets. This will allow for the experimental verification of new magnetic mirror confinement physics issues. This magnet design encompasses both engineering and physics considerations. Engineering considerations include structural integrity, neutral beam access, and diagnostic access; physics issues include the stability and radial transport of the confined plasma. The magnetic field is calculated using the EFFI magnetic code, and the plasma stability and distortion are calculated using the TEBASCO plasma stability field code. The magnet design allows the axisymmetric throttle mirror to be varied from the end cell mirror value of 2 to a peak of 6 T.